THE AMERICAN MINERALOGIST
JOURNAL OF THE MINERALOGICAL SOCIETY OF AMERICA

Vol. 17 SEPTEMBER, 1932 No. 9

BAVENITE, A BERYLLIUM MINERAL, PSEUDOMORPHOUS AFTER BERYL, FROM CALIFORNIA*

WALDEMAR T. SCHALLER AND JOHN G. FAIRCHILD
U. S. Geological Survey, Washington, D. C.

ABSTRACT

Bavenite has been identified from a gem tourmaline mine at Mesa Grande, California. This is the second recorded occurrence of this mineral, previously described from Baveno, Italy. Bavenite is a beryllium mineral, with about 3 per cent of BeO. The Italian bavenite also contains beryllium, not previously recognized. Three new crystal forms are determined; the optical properties are given, correcting an error in the optical orientation as published; and the chemical analysis leads to the formula $9SiO_2 \cdot Al_2O_3 \cdot BeO. 4CaO \cdot H_2O$, with some uncertainty as to the exact ratio of the SiO_2 and H_2O. The California occurrence is a new pseudomorph after beryl.

INTRODUCTION

Bavenite was described by Artini[1] in 1901, as groups of prismatic crystals in pegmatitic druses in the granite of Baveno, Italy. No further records of additional occurrences were found in the literature. Artini assigned to the mineral the formula $3CaO \cdot Al_2O_3 \cdot 6SiO_2 \cdot H_2O$, having no reason for suspecting the presence of beryllium. Some years ago Mr. E. Schernikow of San Francisco, kindly presented to one of the writers (W.T.S.) a specimen of a fine-grained white pseudomorph after a flattened crystal of beryl, from the Himalaya mine, Mesa Grande, San Diego County, California, the mine famous for its many wonderful tourmalines and other associated minerals. Only recently did an opportunity occur for analyzing this pseudomorphous mineral, for it was realized that being an alteration product of beryl it might contain beryllium and one of the writers (J.G.F.) had just finished a comparison of the various analytical methods for separating small quantities of beryllium from aluminum. The analysis of the mineral from Mesa Grande showed it to contain 2.67 per cent BeO, but otherwise it is identical in composition with the bavenite from Italy.

---

* Published by permission of the Acting Director, U. S. Geological Survey.

[1] Artini, Ettore, Di una nuova specie minerale trovata nel granito di Baveno: *Atti d. Reale Accad. dei Lincei, Rendi., classe sci. fis., mat. e nat.*, vol. **10**, pp. 139–145, 1901. Abstr. in *Zeitschr. f. Kryst. u. Min.*, vol. **37**, pp. 389–391, 1903. There are two errors in the abstract: The cleavage is given as (100), it should read (010); and ptilolith should read pilonith.

Spectrographic tests made by George Steiger, on two specimens of bavenite from Baveno, Italy, indicate that the Italian bavenite contains fully as much beryllium as the mineral from California.

The occurrence at Mesa Grande establishes another pseudomorphous change after beryl. Dana lists kaolin, mica, limonite, and quartz as pseudomorphous after beryl. Other alterations are rosterite and pseudosmaragd. The compact fine-grained white earthy bavenite, pseudomorphous after beryl, from Mesa Grande, California, resembles kaolin in general appearance and it is possible that such pseudomorphous bavenite, from other localities, has erroneously been called kaolin.

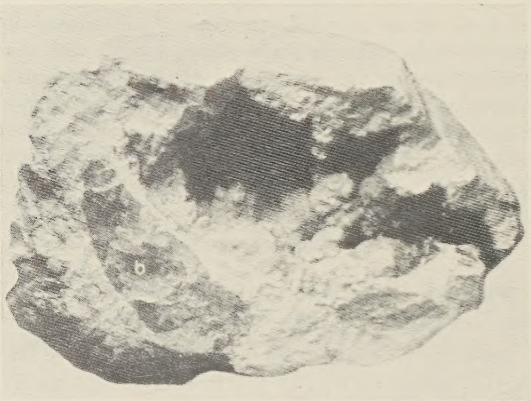


FIG. 1. Specimen of bavenite from Mesa Grande, California, pseudomorphous after beryl. Residual beryl marked *b*. Natural size.

OCCURRENCE

The specimen, shown in natural size in Fig. 1, measures 3 inches across horizontally and is slightly over 1½ inches high. The original crystal of beryl was pink, as evidenced by the residual material (*b*, Fig. 1) embedded in the bavenite, and was a flattened crystal with large faces of *c*(0001) and *s*(11$\bar{2}$1), probably similar in shape to the crystals of beryl shown by Ford[2] in his Figures 1, 4, 5. Both faces of the base (0001) are present on the pseudomorphous specimen from California; the only other recognizable face, is the one shown in the upper right corner of Fig. 1, evidently a face of $s(11\bar{2}1)$. Measured $c \wedge s = 43°–44°$ (Calc. 44°56′).

---

[2] Ford, W E., Some interesting beryl crystals and their association: *Amer. Jour. Science*, 4th ser., vol. **22**, pp. 217–223, 1906.

The original crystal of beryl has been almost completely changed to a fine-grained, compact, white chalky-looking material, soft, easily rubbing off and soiling the fingers. Considerable albite and smaller quantities of pink tourmaline, lepidolite, quartz, and black specks of manganese oxide are partially embedded in the outside of the specimen. Although showing no definite structure to the unaided eye, an examination with a hand lens on a freshly broken surface shows that much of the bavenite has a fibrous character.

The specimen was broken in halves, with the hope of finding some unaltered beryl remaining in the center. This hope was fulfilled as such a residual mass of pink beryl, slightly over an inch long, was found embedded in the white bavenite. (See (*b*) Fig. 1.) This beryl is typical of the alkali-containing beryls, with refractive indices slightly higher than ordinary beryl. This residual pink beryl has $\omega = 1.585$, $\epsilon = 1.578$. Ford[3] found $\omega = 1.58157$ for a pink beryl from Mesa Grande with 1.48 per cent alkali oxides (K_2O, Na_2O, Li_2O, with no Cs_2O). When the pseudomorphous crystal was broken in two, a cavity was found in its center, whose walls are composed of aggregates of fibrous spherulites of bavenite. The cavity is somewhat flattened parallel to the base of the original beryl crystal. The compact bavenite surrounding the cavity is fibrous, mostly radiating but partly parallel. The surfaces of the spherulites of bavenite in the cavity are covered with minute bristling lath-shaped prismatic crystals, which, with the hand lens, can be seen to be terminated by long narrow dome faces, as shown in Figures 2 and 3.

A small cavity on the surface of the specimen, probably formed by the removal of a crystal of tourmaline, was lined with minute terminated crystals, on one side in parallel grouping and on the other sides in radiating fibrous masses.

Part of the mass of residual beryl showed the penetrating character of the bavenite as fibrous masses projecting irregularly into the beryl and as replacing the beryl along the many fractures.

---

[3] Ford, W. E., The effect of the presence of alkalies in beryl upon its optical properties: *Amer. Jour. Science*, 4th ser., vol. **30**, p. 129, 1910.

CRYSTALLOGRAPHY

Before measuring the minute crystals of bavenite from California, four crystals from the type locality at Baveno, Italy, were measured. These agreed in habit, form development, and angular values with those given by Artini. Each of the flattened crystals was terminated by two dome faces on both the front and the rear sides, as illustrated by Artini in his crystal drawing of bavenite (his Fig. 1). However, only one of these forms corresponds to the dome (101) given by Artini, the other face being a new dome (201), present on each of the four crystals measured. Artini's form (103) was not observed; he describes it as rather rare being found only on three of his best crystals with one face on each crystal. As the dome (201) was present on each of the four measured crystals from Italy as well as on those from California, it would appear to be a characteristic form for bavenite and it seems strange that it was not present on the crystals measured by Artini. In addition to the forms given by Artini, with the exception of (103), the clinopinacoid (010) and the clinodome (012) as well as the new dome (201), were also observed on the crystals from Baveno, Italy.

Artini has shown that the crystals are pseudo-orthorhombic, being monoclinic, twinned on the front pinacoid $a(100)$. As a result, the crystals appear orthorhombic in symmetry, on the one terminated end.

Two different orientations are suggested by Artini. Plotting the measurements (by W.T.S.) direct on a gnomonic projection, it is seen that the best orientation is the one in which his form (103) becomes the base (001). The only terminal form, in addition to those in the front dome zone $(001) \wedge (100)$, then becomes the clinodome (012), retaining the indices of the two prisms as given by Artini.

The crystal elements of bavenite are then: $a:b:c = 1.2006:1:0.5230$, $\beta = 78°08'$ (Artini). The table below gives the calculated angles and the average of the measured angles. All the measurements were poor and not suitable for calculation of new crystal elements as they showed variations of several degrees. However, the averages of the measured angles are, except for the prism (210), very close to those given by Artini. Thus, the ϕ angle for $m(110)$ is 40°39′ (Artini, 40°24′), the ρ angle for $u(101)$ is 33°12′ (Artini, 33°14′). From the ϕ and ρ measurements of $e(012)$, the value of β is obtained direct and found to be 78°12′ (Artini 78°08′). Only the measurements of *l*(210) are considerably at variance with the calculated value.

Of the forms listed, the following are new: *b*(010), *d*(201), *e*(012). All three are present on the crystals from Italy; the form *d*(201) is also present on the crystals from California.

Forms and Angles of Bavenite

(New forms are starred)

$a=1.2006$ $p_0'=0.4451$
$c=0.5230$ $q_0'=0.5230$
$\beta=78°08'$ $e'=0.2101$

Forms	Calculated		Measured					
			Italy (Artini)		Italy (Schaller)		California (Schaller)	
	ϕ	ρ	ϕ	ρ	ϕ	ρ	ϕ	ρ
a(100)	90°00′	90°00′	....	....	90°00′	90°00′	90°00′	90°00′
**b*(010)	0 00	90 00	....	....	2 33	90 00	....	....
c(001)	90 00	11 52	....	(a)11°52′	....	....	....	....
m(110)	40 24	90 00	(a)40°24′	....	40 39	90 00	....	....
l(210)	59 34	90 00	60 34	....	63 09	90 00	61 09	90 00
u(101)	90 00	33 14	(a)33 14	....	89 45	33 12	90 00	35 25
**d*(201)	90 00	47 44	....	....	90 07	48 19	90 00	48 58
**e*(012)	38 47	18 33	....	....	37 19	19 01	....	....

(a) Used as the three fundamental angles by Artini for the calculation of the axial ratio.

The combinations on the four measured crystals of bavenite from Italy are:

(1) *a, b, m, l, u, d, e.*
(2) *a, b, m, l, u, d.* (Fig. 2.)
(3) *a, –, m, l, u, d.*
(4) *a, b, m, l, u, d, e.*

The two measured crystals from California have the combinations:

(1) *a, m?, l, d.*
(2) *a, m?, l, u, d.* (Fig. 3.)

The form *m*(110) could not be measured on the crystals from California, as the entire zone is strongly striated vertically but there is a decided increase in brightness in the prism zone for the proper position for this form. The measurements for the new forms are as follows:

ϕ for *b*(010) = 1°27′, 2°18′, 3°54′
ρ for *d*(201) = 47°30′, 47°08′, 48°15′, 49°55′, 48°45′.

The two best measurements for *e*(012) are given in the first two lines below, followed by three additional measurements (in parenthesis) of extremely minute faces of *e*(012) which gave no reflection but were measured by their position of maximum brightness.

Measurements of *e*(012)

ϕ	ρ
37°39′	19°30′
36 59	18 32
(42°)	(22°)
(32°)	(20°)
(33°)	(19°)

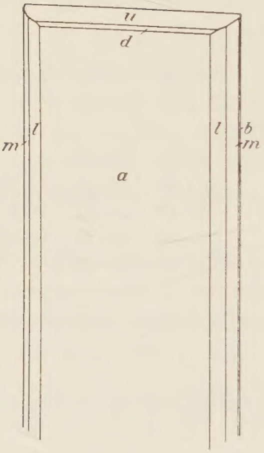


Fig. 2

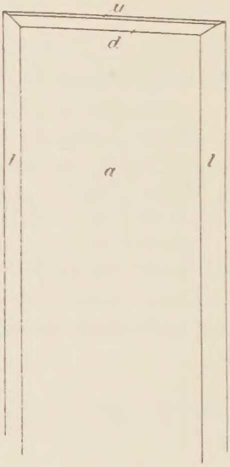


Fig. 3

Fig. 2. Bavenite crystal from Italy. Forms: *a*(100), *b*(010), *m*(110), *l*(210), *u*(101), *d*(201). The crystals are monoclinic, twinned on *a*(100) and consequently simulate orthorhombic symmetry.

Fig. 3. Bavenite crystal from California. Forms: *a*(100), *l*(210), *u*(101), *d*(201).

The habit of the crystals from the two localities is very similar. Both are platy prismatic, the front pinacoid *a*(100) being the dominant form. The entire prism zone is strongly striated. The termination is determined by front domes somewhat striated parallel to their intersection; Artini gives these as (101) and (103) which in the orientation here chosen become (101) and (001). In the four crystals from Italy here described, no face of (001) (Artini's (103)) was observed, but each crystal had faces of *d*(201), a form not found by Artini. Two of the crystals also had minute faces of *e*(012). On the specimen studied (from Italy) the crystals have the characteristic combination *a*, *b*, *m*, *l*, *u*, *d*, Fig. 2. The crystals from California are very similar showing *a*, *l*, *u*, *d*, Fig. 3. In general the faces of *u*(101) are larger than those of *d*(201) on the crystals from Italy whereas on those from California, the faces of *d*(201) are the larger, *u*(101) being a mere line face. Three faces of *e*(012) were measured at one end of one of the crystals from Italy, showing that the crystal is twinned on *a*(100).

OPTICAL PROPERTIES

Observations under the microscope, with determinations of the quantitative values, have shown the complete identity of the bavenite from the two localities. The crystals from California are so minute, about a tenth of a millimeter wide, that their monoclinic symmetry would probably not have been noticed. But a special study of the crystals has shown that their apparent orthorhombic symmetry is due to twinning on the front pinacoid *a*(100) and

OPTICAL PROPERTIES OF BAVENITE

	Italy			California			Average
				Schaller		[b]Ross	
	Artini	[a]Larsen	Schaller	Fibers	Crystals	Fibers	
α..........	....	1.578	1.580	1.580	1.579	1.580	1.579
β..........	1.580	1.579	1.582	—	1.581	—	1.581
γ..........	....	1.583	1.590	1.588	1.589	1.587	1.587
2V..........	47°	Small	....	....	....	58°	
2E..........	$78\frac{1}{2}$°	....	....	...	....	103°	
Sign........	+	+	+	....	+	+	+
Elong.......	....	....	—	—	—	—	—
Ext.........	2°	Very small	....	....	2°	....	2°
Orientation..	$Z=b$	$Z=b$	$Z=b$	....	$Z=b$	....	$Z=b$

[a] Larsen, E. S., The microscopic determination of the nonopaque minerals: *U. S. Geol. Survey.*, Bull. **679**, p. 44, 1921.

[b] Personal communication.

cleavage fragments parallel to $b(010)$ show this twinning with the two parts extinguishing about 4° apart with consequent extinction against the vertical axis of 2°.

The determinations of the optical properties of bavenite are summarized in the table above. The mineral is colorless, nonpleochroic, and shows no differential absorption.

Artini has the axial plane in the wrong position in his Fig. 2. He gives it as parallel to the elongation whereas it is across the elongation, being approximately parallel to the basal pinacoid. The obtuse bisectrix (X) emerges nearly normal to (100) and the acute bisectrix (Z) emerges normal to (010). This relationship, namely that the axial plane lies nearly normal to the elongation and not parallel to it, was determined on bavenite crystals from Italy as well as on those from California. The correct orientation is given by Larsen. With the crystallographical axes used in this paper, namely $a:b:c = 1.2006:0:0.5230$, $\beta = 78°08'$, the optical orientation of bavenite is:

$X \wedge a$ axis $= 10°$ (above)
$Y \wedge c$ axis $= 2°$ (in front)
$Z = b$ axis

CHEMICAL COMPOSITION

Being pseudomorphous after beryl, the bavenite from California, is naturally thought of as containing beryllium and spectrographic tests, kindly made by George Steiger, showed definitely that beryllium is present, in quantity greater than a trace. Chemical separation and determination (by J.G.F.) verified the presence of beryllium to an extent of nearly 3 per cent.

Additional tests made on two samples of bavenite from Baveno, Italy, (U. S. National Museum Cat. Nos. 85180, the same specimen on which Larsen made his optical determinations, and R4158 (Roebling collection)) showed that they too contained beryllium, in quantity similar to that from California. The results of Mr. Steiger's spectrographic tests on bavenite are given in Fig. 4.

In this figure, the upper black band on each chart, labelled beryllium, shows the four characteristic lines of beryllium at 2494, 2650, 3130, and 3321 Ångstrom units. The upper black band was made with beryllium metal. The correspondence of the four lines of beryllium in the spectrum of each of the three specimens examined, with the beryllium standard lines, at the wave lengths given, is clearly shown. The upper spectrograph of bavenite from

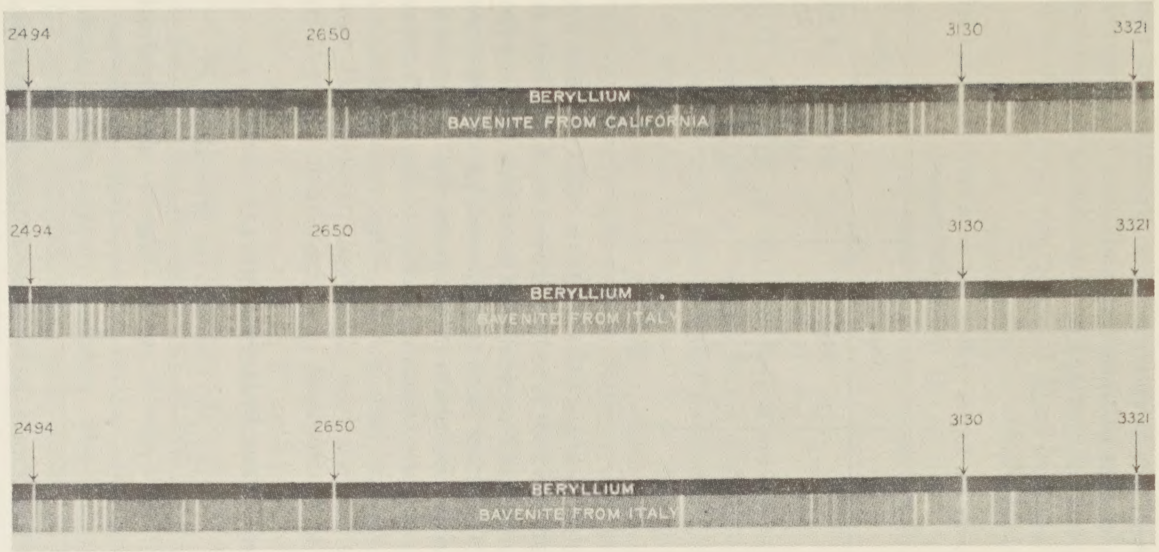


FIG. 4. Charts showing spectrographic identification of beryllium in bavenite from California and from Italy. (Spectrographs taken by George Steiger).

Italy is from specimen U. S. Nat. Mus. No. R4158 and the lower spectrograph is from specimen U. S. Nat. Mus. No. 85180.

A sample of the bavenite from California was prepared for analysis, being carefully purified by hand picking and particularly freed from any admixed beryl. Its analysis is given below with the ratios calculated therefrom.

ANALYSIS AND RATIOS OF BAVENITE FROM MESA GRANDE, CALIFORNIA
[J. G. Fairchild, analyst]

	Analysis	Ratios	
SiO_2	58.40	.9717	8.99 or 9
Al_2O_3	12.16	.1192	1.10 or 1
BeO	2.67	.1068	0.99 or 1
CaO	23.73	.4230	3.91 or 4
H_2O	2.90	.1611	1.49 or $1\frac{1}{2}$
Fe_2O_3	0.10		
	99.96		

The determinations were made in duplicate, with close checks for the CaO and SiO_2. The beryllia was separated from the alumina by the method of Noyes and Bray in which BeO is separated from Al_2O_3 in HCl-ether solution, followed by the treatment of their acetates with chloroform in which the BeO compound is soluble. By this procedure known quantities of BeO were recovered from admixed material high in Al_2O_3. When such a solution containing beryllium is freed from chloroform, treated with turmeric, and then made ammoniacal, a characteristic claret-colored lake is formed.

The loss of water by ignition, was as follows:

TOTAL H_2O LOST AT GIVEN TEMPERATURE, C°.

	110°	150°	300°	450°	550°–600°	Ignition
Percent loss	0.00	0.02	0.04	0.08	0.26	2.90

The ratios indicate the formula $9SiO_2 \cdot Al_2O_3 \cdot BeO \cdot 4CaO \cdot 1\frac{1}{2}H_2O$. As discussed below, it is believed that part of the water is adsorbed and not inherent to the mineral so that the formula for the mineral is written with one H_2O.

A discussion of the formula calculated from Artini's analysis of the bavenite from Italy suggests that the ratio of silica to alumina is only 8:1 and not 9:1. In the analysis of the mineral from California, the ratio of SiO_2 to the other bases, is as follows:

$$\frac{SiO_2}{Al_2O_3}=\frac{8.15}{1.00}$$

$$\frac{SiO_2}{BeO}=\frac{9.10}{1.00}$$

$$\frac{SiO_2}{CaO}=\frac{9.19}{4.00}$$

As, however, the ratio of Al_2O_3 to BeO is not exactly 1:1 but 1.00:0.90, it may be that the determination of beryllia is a little low and that its separation from alumina was not altogether complete. If the true content of beryllia is 0.25 per cent greater than given, namely 2.92 per cent (and the alumina correspondingly lower), then the ratio of BeO to Al_2O_3 becomes 0.1168:0.1168, or exactly 1:1 and the ratio of SiO_2 to Al_2O_3 and to BeO becomes 8.32:1, raising doubt as to the correctness of the ratio of $9SiO_2$.

The analysis of bavenite from Italy is reproduced below, as given by Artini, except that his percentage of Al_2O_3 has been changed, so as to allow for about the same quantity of BeO as is present in bavenite from California and to give a 1:1 ratio of Al_2O_3 to BeO.

The percentage of Al_2O_3 given by Artini, for the bavenite from Italy, is 15.42. Any beryllia present in the mineral would be included with the Al_2O_3. This percentage is nearly the same as that of Al_2O_3+BeO (14.83) determined by Fairchild in the bavenite from California. As the spectrographic examination (see Fig. 4) showed that beryllium was likewise present in the bavenite from Italy, it is assumed that its percentage as beryllia is about the same as in the sample from California, namely about three. It is found by appropriate calculation that the 15.42 per cent of Al_2O_3, given by Artini, can be expressed as being composed of 12.38 per cent Al_2O_3+3.04 per cent BeO, these values giving a 1:1 ratio of the two oxides, as was approximately found for the mineral from California. Adopting these figures and replacing Artini's determination of 15.42 per cent Al_2O_3 by them, his analysis and ratios calculated therefrom, are given below.

ANALYSIS AND RATIOS OF BAVENITE FROM ITALY WITH THE Al_2O_3 CHANGED TO ALLOW FOR THE NECESSARY BeO
[E. Artini, analyst]

	Analysis	Ratios		
SiO_2	56.93	.9472		8.12 or 8
Al_2O_3	12.38	.1214		1.04 or 1
BeO	3.04	.1216		1.04 or 1
CaO	24.47	.4362	.4439	3.80 or 4
MgO	0.12	.0030		
Na_2O	0.29	.0047		
H_2O	2.49	.1383		1.19 or 1
	99.72			

The ratios indicate the formula $8SiO_2 \cdot Al_2O_3 \cdot BeO \cdot 4CaO \cdot H_2O$. The ratios of SiO_2 to the bases are:

$$\frac{SiO_2}{Al_2O_3} = \frac{7.80}{1.00}$$

$$\frac{SiO_2}{BeO} = \frac{7.79}{1.00}$$

$$\frac{SiO_2}{CaO} = \frac{8.54}{4.00}$$

It is possible that in Artini's analysis, not all the silica was separated as such but part may have been included with the alumina, giving a slightly low value for SiO_2. The analysis was made some 30 years ago and the 8:1 ratio of silica to alumina may be due to incomplete separation of all the silica. On the other hand, the sample of bavenite from California—compact, finely fibrous, and partly earthy—may have included in it a small quantity of free silica, such as opal or chalcedony.

The distribution of the reported percentage of Al_2O_3 in the bavenite from Italy, between Al_2O_3 and BeO, is of course arbitrary and the resultant ratio of SiO_2 to either Al_2O_3 or BeO cannot be given too much weight in deciding the valuation of SiO_2 in the formula. The only base left, for such consideration, is lime, CaO. In the analysis of the bavenite from California, the ratio of SiO_2:4CaO is 9.19 whereas in that from Italy, the similar ratio is 8.54, about halfway between 8 and 9.

Two formulas, with either 8 or $9SiO_2$, are thus indicated by the two analyses. The correct quantity of water inherently belonging to the mineral, either 1 or $1\frac{1}{2}$ H_2O, is also in doubt.

A comparison is therefore made between the two analyses of bavenite and the composition calculated from the four possible formulas, the ratio of SiO_2 and H_2O being the doubtful items. The four possible formulas are:

$8SiO_2–1\ H_2O \cdots 8SiO_2 \cdot Al_2O_3 \cdot BeO \cdot 4CaO \cdot H_2O$

$8SiO_2–1\frac{1}{2}H_2O \cdots 8SiO_2 \cdot Al_2O_3 \cdot BeO \cdot 4CaO \cdot 1\frac{1}{2}H_2O$

$9SiO_2–1\ H_2O \cdots 9SiO_2 \cdot Al_2O_3 \cdot BeO \cdot 4CaO \cdot 1\ H_2O$

$9SiO_2–1\frac{1}{2}H_2O \cdots 9SiO_2 \cdot Al_2O_3 \cdot BeO \cdot 4CaO \cdot 1\frac{1}{2}H_2O$

The comparison of the two analyses with the theoretical composition, as calculated from these four formulas, is given in the following table. Each of these four formulas is indicated by the silica and water ratios.

COMPARISON OF THE TWO ANALYSES OF BAVENITE WITH THE COMPOSITION CALCULATED FROM FOUR SIMILAR FORMULAS

	Italy	California	8–1	8–$1\frac{1}{2}$	9–1	9–$1\frac{1}{2}$
SiO_2	56.93	58.40	56.55	55.96	59.42	58.84
Al_2O_3	12.38	12.16	12.00	11.87	11.20	11.10
BeO	3.04	2.67	2.94	2.91	2.75	2.72
CaO	24.47	23.73	26.39	26.12	24.65	24.41
H_2O	2.49	2.90	2.21	3.14	1.98	2.93
MgO	0.12	none				
Na_2O	0.29	n.d.				
Fe_2O_3	....	0.10				
	99.72	99.96	100.00	100.00	100.00	100.00

The ratio of H_2O in the analysis of bavenite from Italy (1.19) is only slightly over 1 and closer to 1 than $1\frac{1}{2}$. On the other hand, the ratio of H_2O for the bavenite from California (1.49) is almost exactly $1\frac{1}{2}$. Nothwithstanding, $1H_2O$ is chosen as correct, as it simplifies the formula of the mineral and the water content of compact fibrous minerals, as determined, is very apt to be higher than the true inherent water content. It is well known that many minerals acquire a small quantity of firmly held adsorbed water during grinding, which is retained to a very high temperature.

Both formulas with $8SiO_2$ contain over 26 per cent of CaO, a value considerably higher than the CaO content in either analysis. The CaO content of the two formulas with $9SiO_2$ contains a percentage value in better agreement with that found. As already stated, one part of H_2O (instead of $1\frac{1}{2}$ parts) is chosen. The formula for bavenite is therefore given as $9SiO_2 \cdot Al_2O_3 \cdot BeO \cdot 4CaO \cdot H_2O$.

SHIFT OF THE PLANE OF PROJECTION IN THE GNOMONIC PROJECTION

F. E. Wright

Geophysical Laboratory, Carnegie Institution of Washington

Abstract

In the gnomonic projection the shift from one plane of projection to another can be accomplished graphically by several different methods; by their use the observer is able to locate the positions of diametral planes and of single points in the new projection. Several new methods, based on the isometric lines and their polar planes, are described briefly, together with the existing methods. The usefulness of the gnomonic projection as an aid in photogrammetric mapping from airplane photographs is emphasized.

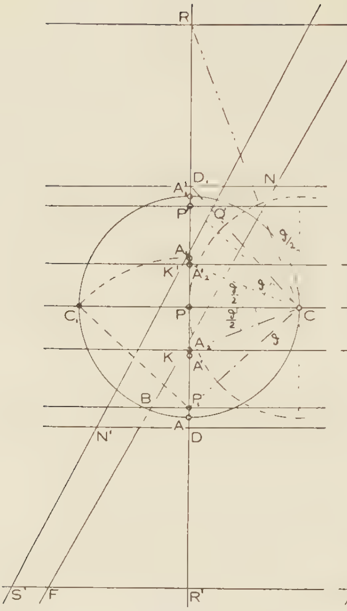
The gnomonic projection is widely used in crystallography, navigation, and other branches of science, for the reason that all great circles on the sphere appear as straight lines in the projection. The plane of projection is the plane tangent to the sphere at a given point called the pole of the projection. In many problems it is desirable to change from one plane of projection to another. This can be done with the aid of a special gnomonic projection plot, or by graphical methods, or by computation. The projection plot, however, is at a disadvantage because, for polar angles exceeding 70°, the plot is so large that it becomes unwieldy. Recourse must then be had to some method of graphical construction or to computation. Several of the graphical methods are known,[1] but others described below appear to be novel and may merit brief description, although they are based on known principles.

In Fig. 1a let the plane of the paper be the plane of projection, tangent at P to the sphere of reference of radius PC. The actual center of the sphere, O, is directly beneath P. The straight line, FNS, represents a great circle in projection and is, in fact, the line of intersection of the diametral plane, whose trace on the sphere is the given great circle, with the tangent plane of projection. The plane of projection is now shifted, so that another direction, OP_1 represented by the point P_1 in the present projection, becomes the pole. The problem is to find the position of the great circle plane, FNS, and of any given point, such as B, in the projection after the rotation. The problem can be solved graphically with the aid of certain construction lines and points indicated in Figs. 1a to 1d.

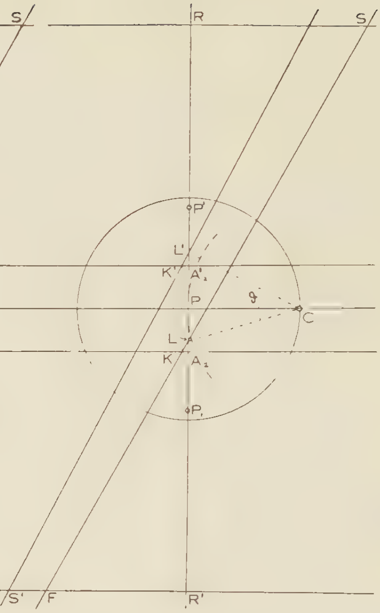
---

[1] V. Goldschmidt, Ueber Projektion und Graphische Krystallberechnung, pp. 67–71, 1887, *Berlin.*

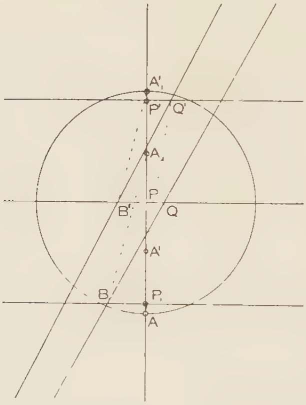
1 a



1 b



1 c



1 d

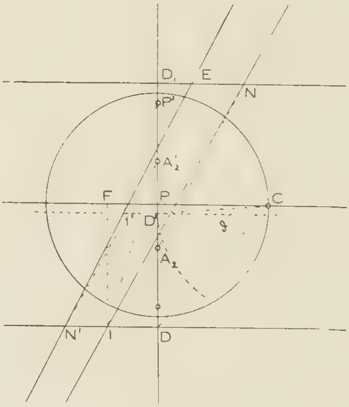


FIG. 1a. In this figure the several constructional lines and points are shown which may serve as aids in determining the positions of zone lines and points in the gnomonic projection after its rotation through a given angle φ.

FIG. 1b. Illustrates the methods for locating the points, L' on the principal line, K' on the isometric line, and S' on the isometric polar line.

FIG. 1c. Indicates how the points, B' on the normal line, and Q' on the new guide line are found.

FIG. 1d. Illustrates the methods for ascertaining the positions of the points, N' on the new prism line, I' on the new prism line after rotation, also the direction of the desired line $N'E$ parallel with the line A_2N.

The shift of the projection from pole P to pole P_1 is essentially a rotation of the projection about the horizontal axis parallel to PC (Fig. 1a), and through the center, O, of the sphere. During this rotation, points in the vertical plane normal to the axis and represented by the *principal line* P_1PP' remain in the plane; also all great circle planes containing the axis of rotation remain perpendicular to the line P_1PP' and their traces in the projection are parallel lines. To measure the angular rotation, rotate the vertical plane P_1PP' about the line P_1P' as an axis and bring the center of the sphere, O, into the plane of projection at C. The actual angle of rotation from P_1 to P is then the angle $PCP_1 = \theta$. On rotation P_1 becomes the new pole and P, the original pole, is shifted to P'. The original equatorial plane, of which P is the pole, becomes the line $N'D$ in the new projection; in like manner the line D_1N, which is the great circle plane normal to P_1, ($P_1CD_1 = 90°$), becomes the equator after the rotation. The line A_2K is midway, in angular measure, between P_1 and P; angle $PCA_2 =$ angle $P_1CA_2 = \theta/2$. On rotation, A_2 is shifted to A_2' and the line A_2K to $A_2'K'$. The line A_2K is important because it represents the line of intersection of the new and old planes of projection; it is common to both projections; similarly the line $A_2'K'$. The points on A_2K retain the same relative positions on $A_2'K'$; thus the point K is shifted to K' and $A_2'K' = A_2K$. In stereophotogrammetry these lines are the *perspective* lines, so named because on them the scales are similar and not distorted.

To find the angle between any two points, as P_1 and B (Fig. 1a), in a given great circle plane bring the center, O, of the sphere to A_1 in the plane of projection by rotating the plane about the line P_1B. The distance P_1O to the center of the sphere is equal to $P_1C = P_1C_1$. Draw $P_1A_1 = P_1C_1$ and find at A_1 the desired position of the center of the sphere brought into the plane of projection. The point A_1 is called the *angle point* of the great circle plane P_1B. The angle P_1A_1B is the angle between the radial lines represented by the points P_1 and B. Similarly A_1', A', A_2 and A_2' are the angle points of the great circle planes PC, $P'Q'$, D_1N, and DN' respectively.

As possible constructional aids we have then the angle point C from which the angle between any two points on the *principal line* $P'P_1$ can be read off directly; the *normal line* PC with its angle point A; the old and new *guide lines* P_1B and $P'Q'$ with the angle points A_1 and A'; the old and new *prism* or *polar guide lines*,

D_1N and DN' with the angle points A_2 and A_2'; the *common* or *perspective lines* A_2K and $A_2'K'$; the *common polar planes* RS and $R'S'$, polar respectively to A_2 and A_2'. With the aid of these constructional elements the observer may choose any two of the following operations to ascertain the position of any given great circle plane or zone line, such as FNS, in the new projection.

(1) The point K, the intersection of the given line with the original isometric line, becomes K' in the new projection. (Fig. 1b). $A_2K = A_2'K'$.

(2) The intercept $R'S'$ on the polar plane to A_2' is equal to the intercept RS on the RS line polar to A_2'. (Fig. 1b). Angles $A_2CR = A_2'CR' = 90°$ (Fig. 1a).

(3) The point L at the intersection of FS with the principal line PP' (Fig. 1b) is shifted to L'; the angle LCL' is equal to the angle of rotation, θ, of the projection.

(4) The angle between P and Q (Fig. 1c) on the normal line is PAQ. Draw through A', the angle point of $P'Q'$, a line parallel with AQ and find Q'.

(5) The angle between P_1 and B is P_1A_1B. Through A_1' draw $A_1'B'$ parallel with A_1B and locate the point B'. (Fig. 1c).

(6) Draw through A_2' a line parallel with IN and locate the point N'. (Fig. 1d). The desired line $N'E$ is parallel with the line A_2N. (Fig. 1d).

(7) The plane ID is shifted to $I'D'$ by rotation of the projection. (Angle $DCD' = \theta$. Fig. 1d). Draw through P', the angle point of $I'D'$, a line parallel with IA_2' and thus locate I'. (Fig. 1d).

The seven points obtained by these different operations are all located on the desired straight line which represents the position of the old line FNS in the new projection. Experience has shown that the position of FNS in the original projection determines, in a measure, the selection of the operations to use in ascertaining the position of the line after rotation of the projection. With the exception of isometric lines and their polar planes the methods are based on the use of angle points of definite construction lines.

To find the position of any given point, I, (Fig. 1d) after rotation of the plane of projection, method *7* is probably the simplest. In the original projection the given point is at the intersection of two coordinate lines, ID and IF. The angle point of ID is at A_2'; after rotation, the line ID is at $I'D'$ whose angle point is P'. The angle between the plane IA_2' and the principal plane, DP', is $IA_2'D$.

Draw through P', the angle point of $D'I'$, a line parallel with IA_2' and locate the point I' on $I'D'$. Angle $I'P'D'$ is then equal to angle $IA_2'D$. Therefore I' is the position of the given point after the rotation.

In crystallography a crystal drawing is made by projecting in parallel perspective the zone axes on a given plane of projection. Thus, if a top view or plan is desired, perpendiculars are erected to the different zone lines in gnomonic projection and the crystal faces are represented as they appear projected orthographically on the equatorial plane. Any other plane of projection is obtained by drawing its trace in the projection, by locating its angle point, and then, by erecting a line perpendicular to the line passing through the angle point and the point of intersection of a zone line with the given trace, the direction of the edge between any two faces in the given zone is obtained. The same directions can be obtained by first rotating the projection so that the desired plane of projection is the equatorial plane and then erecting the normals to the zone lines in their new positions. For planes of projection not too far from the equatorial plane of the original projection, this method is serviceable. It was the first method used for preparing crystal drawings from the gnomonic projection[2] and is analogous to the usual method adopted for preparing a crystal drawing from a stereographic projection. But ordinarily the plane of projection chosen for crystal drawings is near the pole of the original projection and the crystal faces in the central part of the original gnomonic projection are so far away from the pole in the new projection that the standard procedure is preferable, either with or without the aid of a preliminary top view or plan drawing.

In gnomonic charts for great circle sailing the foregoing methods for shifting from one pole of projection to another are useful in preliminary work. The degree of accuracy obtainable is not great because the earth's geoid surface is not strictly spherical.

In phototopographic work the gnomonic projection enters to a certain extent. The photograph of a plane area taken from an airplane is a gnomonic projection of that area on the plane of the negative. If the area is covered with a rectangular network or grid for measuring purposes, an oblique view of the grid shows the lines converging toward definite points on the horizon. The view is, in fact, a gnomonic projection whose plane includes with the original plane an angle equal to the angle between the tilted negative and the ground. By rotating the original gnomonic projection, on which the grid lines are rectangular and equally spaced, through the angle of tilt the new positions of the lines, as they appear on the photographic negative, are obtained.

---

[2] V. Goldschmidt, Ueber Projektion und Graphische Krystallberechnung, pp. 82–85, **1887**, *Berlin.*

In mapping flat areas from airplane photographs the use of the gnomonic projection is an aid to the observer in visualizing the spatial relations involved. The *perspective center* is the center, O, of the projection sphere; the *principal distance* is the radius of the projection sphere. The *principal point* is the pole of the projection; the *principal line* is the vertical P_1PP' of Fig. 1a; the *perspective planes* are great circle planes. The *horizon trace* is the prism or polar guide line D_1N of Fig. 1a. The *horizontal plane* is the equatorial plane of the projection. On the perspective lines the scales are similar and not distorted. The *angle of tilt* is the angle of rotation, θ, of the gnomonic projection plane. Having given the angle of tilt, it is a simple matter for the observer to deduce the directions of grid or other lines in an oblique photograph; and vice versa, to ascertain from an oblique photograph their directions and positions on the horizontal plane of mapping and thus to prepare the map with the aid of the gnomonic projection.

HEAVY MINERALS AS A GUIDE IN STRATIGRAPHIC STUDIES

Fanny Carter Edson, *Tulsa, Oklahoma*

Abstract

Heavy minerals are one of the accepted means of stratigraphic correlation and they have served as an invaluable stratigraphic guide in Mid-continent correlations. Proper well sampling and laboratory methods of analysis to correlate both surface and underground formations are explained. Important geological data that may be deduced from these analyses are suggested. The results obtained from the application of these methods to the study of sandstones of Ordovician age in the Mid-continent oil field are discussed.

Introduction

Several thousand heavy mineral analyses, extending over a period of some years, have been made by the writer, primarily of Ordovician sandstones encountered by wells drilled for petroleum in the Mid-continent field, but also of Ordovician sandstones which out crop in central United States. The results of this work have been of sufficient importance to warrant its continuance.

It seems to the writer that some workers have expected too much of heavy minerals. Is there any one method, if used alone, that is infallible and entirely adequate to correlate one isolated outcrop with another, or the samples encountered by one well with those from another well? Heavy minerals, like fossils, lithology, stratigraphic sequence, evidences of diastrophism and other methods, can be made to serve as a valuable *guide* in stratigraphic studies; the present paper will attempt to suggest a possible explanation for the adverse conclusions in regard to the efficacy of heavy mineral correlations that have been reached by some workers, and to suggest a method that may yield more favorable results.

Acknowledgments

Grateful acknowledgment is made to the Shell Petroleum Corporation for permission to make public the information herein contained, to A. W. Giles, department of geology, University of Arkansas, for invaluable aid in making the photomicrographs and to Sidney Powers for constructive criticism during the preparation of the manuscript.

Sampling

To obtain usable correlations from heavy mineral analyses, let it be assumed that several wells are drilled near together in a sedimentary basin, through a complete normal succession of beds in a given formation, and that an additional series of wells, cutting the same beds, is drilled from the center toward the margin of the basin. Samples should be taken at five foot intervals in all the wells, records kept of the lithology of all strata penetrated, and analyses made of each sandstone sample. At the margin of the basin, samples should likewise be collected at five foot intervals across the outcrop of the same succession of beds, preferably at several different localities, and analyses made of the outcropping sandstones.

Analyses

In making the analyses, it has been found advisable to take cognizance of several factors such as position within the formation and the lithology of the bulk sample, component heavy minerals, percentage in which each is present, size, assortment, and shape of the mineral grains. Besides giving the location and depth (stratigraphic position) of a sample, a typical analysis might read as follows: "sandstone, little green shale; zircon 45 per cent, tourmaline 40 per cent, barite 5 per cent, rutile 5 per cent, garnet 3 per cent, anatase 2 per cent. Grains irregular in size. Large, well rounded. Small, angular to subangular. Tourmaline larger than zircon. Barite secondary." Such analyses, made of the well and outcrop samples described above, should be tabulated with the stratigraphically highest analysis at the top of the table.

Facts Deduced From Analyses

Tables of heavy mineral analyses permit correlation and interpretation of geologic conditions of sedimentation such as is listed below:

1. The complete lithologic sequence, in descending order, is for example: dolomite; sandy dolomite; coarse sandstone; dolomite; irregular-grained, round and frosted sandstone; fine, even-grained, subangular, less frosted sandstone; green and maroon shale; sandy green shale; coarse sandstone; dolomite.

2. The first bed of an objective group encountered at one locality is not necessarily the bed at the top of the sequence in another locality, or some of the beds lower in the sequence may be absent

locally. Such conditions suggest unconformities and periods of uplift.

3. If, when uplift or erosion has interrupted the normal stratigraphic relationship of the beds at two different localities, only a few analyses were made at each locality, the analyses might be very dissimilar and lead to the conclusion that the analyses were of different formations. If, however, many samples were taken at five foot intervals and analyzed as described above, the membership of the two beds in the same formation and their relationship to each other would be entirely clear.

4. The same component minerals occur over and over again in beds of different age; perhaps no bed has an unusual and diagnostic mineral or suite of minerals.

5. The heavy mineral grains in one sandstone are irregular in size and shape; in another sandstone the same minerals are very uniform in size and shape; the two sandstones can, therefore, be distinguished one from another in spite of the community of their component minerals.

6. The first sandy dolomite in the group is characterized by analyses which are similar wherever this member is present.

7. The analyses of this sandy dolomite differ from those of the underlying pure sandstone member.

8. The analyses of the first pure sandstone member fall into a distinct type, as do those of the other sandstones in the succession, and each has some diagnostic difference from the other.

9. A certain lithologic type of sandstone within the group may always yield similar analyses, in these cases, a relationship between the lithology of a sandstone and its heavy mineral content can be established.

SUMMARY

The writer admits that the same minerals may be present in each standstone analyzed, that the relative percentages are as variable within any single formation as they are throughout the entire group of formations, that those minerals which seem to be present in a single formation occur too infrequently to be conclusively diagnostic, that entirely different heavy minerals may occur in the same formation in different parts of a given area, and wishes to emphasize the fact that a few analyses made of haphazard samples from widely separated outcrops would be of little or no value for correlative purposes.

The writer does not agree, for example with the statements that it is impossible to discriminate between the Lamotte, Roubidoux, Jefferson City, Cotter, St. Peter and Pennsylvanian sandstones by means of heavy mineral analyses,[1,2] nor with the statement that heavy mineral analyses are valueless for long range correlations.[3]

HEAVY MINERALS IN THE MID-CONTINENT REGION

Experience in the Mid-continent region has shown that the analyses of Ordovician, Mississippian and Pennsylvanian sandstones, each have distinctive group characteristics. It is, therefore, entirely possible to determine that even an isolated analysis is of an Ordovician, or Mississippian, or Pennsylvanian sandstone; it is, also, not difficult to recognize that an analysis has been made from a sandstone derived from an older, analyzed bed.

The most notable fact that has been observed from extensive sets of heavy mineral analyses made of Mid-continent sandstones, laid down in one depositional province, is that the heavy mineral zones, even within a single sandstone, are very thin (measured in tens of feet) in a vertical direction, and remarkably persistent horizontally for miles.

ORDOVICIAN SANDSTONES

Many analyses of buried Ordovician sandstones in the Mid-continent oil fields and of outcropping Ordovician sandstones in the Arbuckle Mountains of northeastern Oklahoma, the Ozark region in Arkansas and Missouri, and along the Mississippi and tributary rivers in Illinois, Wisconsin, Iowa and Minnesota have made the following observations possible:

1. Exact well-to-well correlations within a given oil field.
2. Formation correlations from oil-field to oil-field.
3. Correlations from the wells drilled for oil to outcrops in the Arbuckle mountains and in northeastern Oklahoma.
4. Correlations from the outcrops in northeastern Oklahoma to those in Arkansas, Missouri and the Mississippi River valley including the type St. Peter sandstone in Minnesota.

[1] Cordry, Cletus D., Heavy minerals in the Roubidoux and other sandstones of the Ozark region, Missouri: *Journal of Paleontology*, Vol. **3** (1929), No. 1, p. 82.

[2] Grawe, Oliver R. and Cullison, James S., A study of sandstone members of the Jefferson City and Cotter formations at Rolla, Missouri: *Journ. Geol.*, Vol. **XXXIX,** No. 4, May-June, 1931, p. 323.

[3] Twenhofel, W. H., Personal communication.

5. Establishment of overlaps, disconformities and erosional periods.

6. Determination of the character of the source rock, direction from which the sediments were derived, methods of transportation, and the conditions and environment of deposition.

CONCLUSION

In conclusion, the writer calls attention to the fact that the same component heavy mineral grains may be common to sandstones of different age, that the relative percentages of these minerals may vary as much within a given formation as between different formations, but believes that if enough samples are properly taken and analyzed, the community of mineral grains does not preclude the use of heavy minerals as a guide in stratigraphic correlations, and has proved the value of this type of analysis by work in the Mid-continent region.

EXAMPLES

SAMPLE 1

Heavy minerals from a sandy limestone bed near the middle of the Tulip Creek formation of Ordovician age, cropping out in section 21, T 2 S, R 1 E, Arbuckle Mountains, Oklahoma.

Analysis:	Zircon	65 per cent
	Tourmaline	13 “ “
	Rutile	7 “ “
	Garnet	5 “ “
	Hornblende	1 “ “
	Anatase	6 “ “
	Unknown “*X*”	3 “ “

Grams are irregular in size and shape.

SAMPLE 2 (Fig. 1)

Heavy minerals from a sandstone at the base of the Tulip Creek formation of Ordovician age cropping out in section 21, T 2 S, R 1 E, Arbuckle Mountains, Oklahoma

Analysis:	Zircon	25 per cent
	Tourmaline	75 “ “
	Rutile	present
	Garnet	present
	Topaz	present
	Epidote	present
	Anatase	present
	Unknown “*X*”	present

Grains are large, uniform in size, and well rounded.

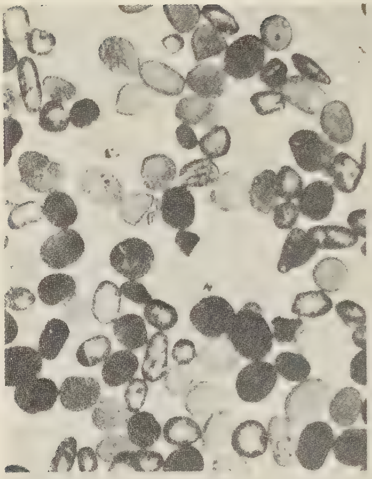


FIG. 1

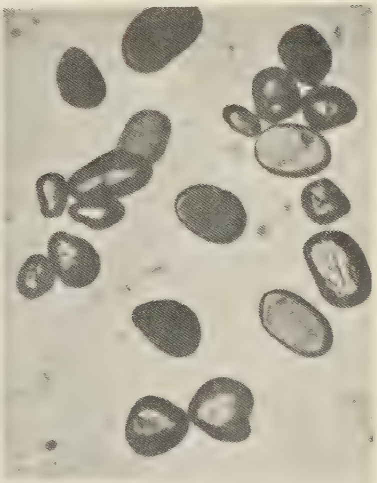


FIG. 2

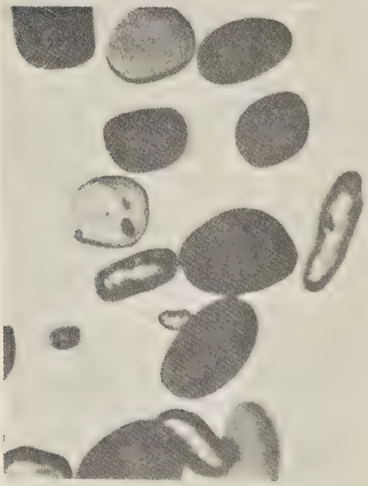


FIG. 3

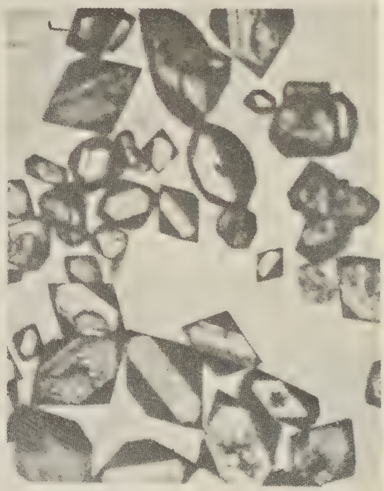


FIG. 4

Sample 3

Heavy minerals from Ordovician sandstone between 3490 and 3508 feet, encountered by Sinclair Oil and Gas Company's Gardner No. 1, section 6, T 4 N, R 6 E, Oklahoma (about 40 miles northeast of Sample 2).

Analysis:	Zircon	17 per cent
	Tourmaline	80 " "
	Garnet	1 " "
	Rutile	1 " "
	Fluorite	1 " "

Grains large, even in size, and well rounded.

Sample 4

Heavy minerals from Ordovician sandstone between 4350 and 4360 feet, encountered by Gypsy Oil Company's Barkus No. 9, section 6, T 8 N, R 6 E, Greater Seminole area, Oklahoma (24 miles north of Sample 3).

Analysis:	Zircon	45 per cent
	Tourmaline	51 " "
	Barite	4 " "
	Rutile	present

Grains large, even in size, and well rounded.

Sample 5 (Fig. 2)

Heavy minerals from outcrop of Ordovician Burgen sandstone in section 11, T 20 N, R 24 E, northeastern Oklahoma (about 100 miles northeast of Sample 4).

Analysis:	Zircon	27 per cent
	Tourmaline	68 " "
	Anatase	4 " "
	Rutile	1 " "

Grains large, even in size, and well rounded.

Sample 6

Heavy minerals from a sample collected 3 feet above the base of the Ordovician St. Peter sandstone outcrop at Pilot Knob, Izard County, Arkansas.

Analysis:	Zircon	26 per cent
	Tourmaline	71 " "
	Anatase	3 " "

Grains large, even in size and well rounded.

Sample 7

Heavy minerals from the Ordovician St. Peter-Joachim contact zone at outcrop on highway 69, 2 miles southeast of Mount Pleasant, Arkansas.

Analysis:	Zircon	56 per cent
	Tourmaline	41 " "
	Rutile	1 " "
	Anatase	1 " "
	Unknown "*X*"	1 " "

Grains mostly very small, subangular. Some larger and better rounded.

SAMPLE 8 (Fig. 3)

Heavy minerals from a bed in the middle of the lower half of the Ordovician St. Peter sandstone outcrop in south half of section 12, T 30 N, R 12 E, Cape Girardeau County, Missouri.

Analysis:		
	Zircon	24 per cent
	Tourmaline	73 " "
	Hornblende	2 " "
	Anatase	1 " "

Grains large, even, well rounded.

SAMPLE 9

Heavy minerals from near the middle of the Ordovician St. Peter sandstone encountered by a water well drilled at Bowling, Green, Pike County, Missouri.

Analysis:		
	Zircon	34 per cent
	Tourmaline	63 " "
	Spinel	2 " "
	Anatase	1 " "

Grains mostly large, even, well rounded. Some zircons smaller, subangular.

SAMPLE 10

Heavy minerals from a bed 4 feet above the Mississippi River and 30 feet below the top of the Ordovician St. Peter sandstone outcrop of the University of Minnesota campus, Minneapolis, Minnesota.

Analysis:		
	Zircon	39 per cent
	Tourmaline	46 " "
	Ilmenite (?)	10 " "
	Staurolite	4 " "
	Garnet	1 " "

Grains large, fairly even, quite well rounded.

SAMPLE 11 (Fig. 4)

Heavy minerals from basal Kinderhookian sand encountered between 3465 and 3472 feet by Tatlock Oil Company's Goldner No. 1, section 6, T 29 S, R 2 E., Kansas.

Analysis:		
	Zircon	100 per cent

Perfect euhedral crystals.

NOTE ON GRÜNERITE FROM THE LAKE SUPERIOR REGION

STEPHEN RICHARZ, *Techny, Illinois*

A recent publication contained certain statements on grünerite from the Lake Superior Region which should not be passed without comment. Sundius[1] describes as grünerite a specimen of amphibole labeled, "Bijiki Schist, Michigamme." Others would prefer to call such a mineral, containing 12 per cent MgO, cummingtonite. In any case, it is quite a different amphibole from the grünerite examined by the writer which came from Mount Humboldt, Michigan, and was found at other places in the Marquette district; likewise on the Mesabi Range in Minnesota. It has uniform optical properties, the highest refractive index being 1.700 or a little higher and the double refraction is 0.034, thus differing considerably from the cummingtonite mentioned by Sundius which has a gamma index of 1.686 and a birefringence of 0.031. Nevertheless, his description is of interest as it illustrates the fact that there are other varieties of iron-rich amphiboles in the "Iron Formations" of the Lake Superior Region, as was pointed out by the writer of this note at the Toronto Meeting of the Mineralogical Society of America, in December, 1930.

However, the mineral described by Sundius is by no means the common amphibole at Michigamme. The writer was permitted to examine a specimen of typical grünerite kept in the petrographic laboratory of the University of Chicago, which is labeled: "Grünerite Schist, Bijiki Schist, just south of western end of Michigamme Mine." Moreover, my friend Mr. Afuhs collected other specimens for me of the Bijiki Schist from the same mine. The grünerite in all of these samples is of especial interest, because the optical properties are intermediate between Mount Humboldt grünerite and that of Collobrières, France. The indices are: $\alpha=1.677$, $\beta=1.697$, $\gamma=1.714$. A chemical analysis would be very desirable, but it would be a difficult task to separate the very minute blades of grünerite from the magnetite dust which is everywhere present. Also garnet, biotite, chlorite, blue-green amphibole and quartz are intimately interwoven with the grünerite. One would be justified in inferring from the higher indices of refraction a higher percentage of iron in this grünerite than in that of Mount Humboldt.

---

[1] N. Sundius, The optical properties of manganese-poor grünerite and cummingtonite compared with those of the manganiferous members: *Am. J. Sci.*, **21**, 330, 1931.

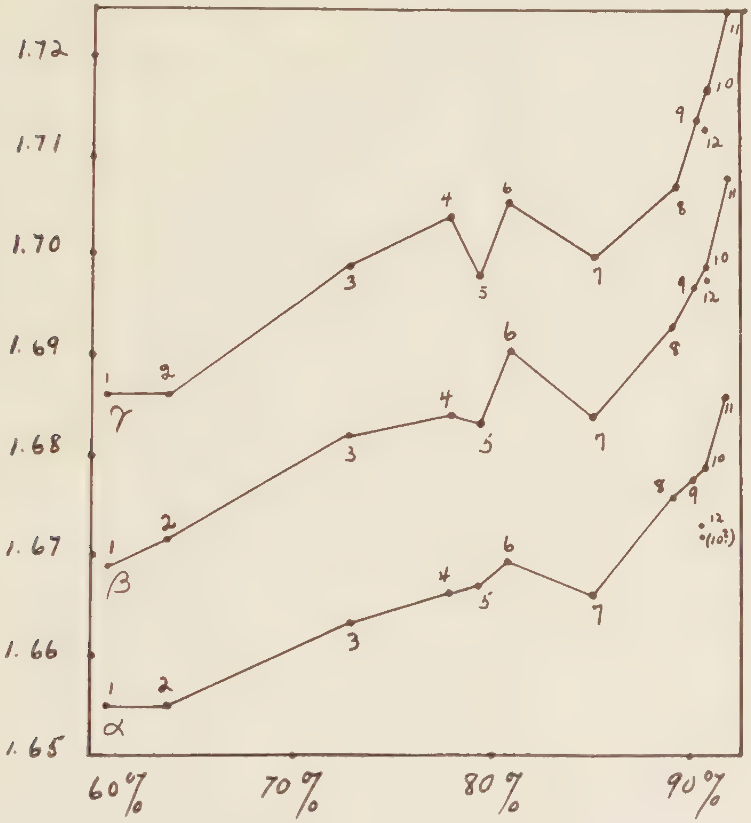
In the course of his paper, Sundius questions the accuracy of my analysis made on pure grünerite from Mount Humboldt. He regards as unusual the 1.25 per cent of alkalies. The alkali determinations were made in the laboratory of the U. S. National Museum by Mr. Earl V. Shannon and their accuracy cannot be questioned. In the meantime Harry V. Warren analyzed grünerite from the Pyrenees.[2] He finds 1.35% of alkalies (average of two analyses), i.e., 0.1% more than in the Mount Humboldt grünerite. At the same time these analyses show that my MgO determination is by no means too low, as Sundius suggests. Warren's average is 3.05%, while the Collobrières grünerite, according to Kreutz, contained 2.61% MgO. Comparing the gamma indices of the three grünerites from Mount Humboldt, Pyrenees, Collobrières, the 4.06% MgO in the first specimen would seem rather too high than too low. I was aware nevertheless that there was a defect in my analysis as the sum total was too low. A recent redetermination of silica resulted in a higher recovery than formerly, 49.90%, which brings up the total to 100.25%. The original error was due to insufficient evaporation in porcelain dishes. In the redetermination platinum was used and the recovery was then complete and uncontaminated. As a consequence, there is no opportunity for more than 4% MgO; nor did several direct determinations result in a larger amount of this oxide.

Furthermore, the agreement, with the formula as proposed for such amphiboles by Schaller, and since confirmed by Kunitz and B. E. Warren, may be regarded as an indirect confirmation of the accuracy of the analysis. According to the method advised by the latter, it was found that the sum of Si and Al amounts to 8.15, that of the metal-atoms 7.01, and of the H-atoms 1.82; indeed a very close approximation to the theoretical formula, closer than in most amphiboles. The grünerite of Collobrières, calculated in the same way, gave 7.86:7.16:2.44.

If Sundius prefers two old analyses of grünerite schists with their unknown impurities, to an analysis of the pure mineral, he should not be surprised if his calculations are to be regarded as quite doubtful. Sundius does not mention in his recalculated analyses any water, which is evidently essential to an amphibole. Nor does he take into account the "loss" of 0.67 and 1.40% respectively, as given in the analyses referred to (U. S. Geol. Survey, Monograph 28, p. 338). Such a loss is highly puzzling. Grünerite ignited does not lose weight, but gains. I found a net gain of 1.73% after igniting

---

[2] Harry V. Warren, An occurrence of grünerite at Pierrefitte, Hautes-Pyrénées, France: *Min. Mag.*, **22**, 477, 1931.



$H_2\ (Fe,\ Mn)_7\ Si_8\ O_{24}$

the Mount Humboldt material, although 1.71% of water was driven off. Nearly all FeO was changed to Fe_2O_3. A loss would be possible in the second analysis on account of the presence of CO_2, but not in the third although for this one the highest loss is recorded. Thus these old analyses are of very doubtful value. Dr. Schaller writes concerning them as follows: "It has been my considerable experience that it does not pay to try to interpret these old analytical data, especially if the figures, finally given, have been corrected by plus and minus items due to other constituents. One never knows whether the final result means anything. Personally, I would not use Melville's figures, simply because the 'loss' is too indefinite." For the somewhat higher amount of magnesia in these analyses, a blue-green amphibole may be responsible which frequently was seen in grünerite schists.

Many attempts have been made to find a simple relationship between the optical properties of amphiboles and their chemical compositions. For the majority of the iron-rich amphiboles this relationship is well established. However, it cannot be denied that there are still a few points which prevent us from representing the optical properties as simple functions of the chemical compositions. In the accompanying diagram these relations in twelve amphiboles, of rather high iron-manganese content, are illustrated. Following Kunitz, the percentage of $H_2(Fe, Mn)_7Si_8O_{24}$ to $H_2Mg_7Si_8O_{24}$ was calculated and the former used as abscissa. Instead of drawing straight lines, the points indicating the refractive indices are connected with zigzag lines, which bring out clearly minor deviations.

For the grünerites in the strict sense of this term, with which the writer is especially concerned, the relationships sought can be represented by almost a smooth curve, if we take into account some new determinations. In a previous paper (this Journal, vol. **12,** p. 353, 1927), the writer stated the opinion that the Collobrières grünerites might represent varying compositions and optical properties. The latter has been partly confirmed. In a specimen preserved in the U. S. National Museum the refractive indices were found by the writer to be higher than those determined by Kreutz. To make sure of this fact, Dr. Clarence S. Ross of the U. S. Geological Survey was asked to check these indices. The values found were: $\alpha=1.686$, $\beta=1.708$, $\gamma=1.725$, all ± 0.002. In the specimen examined the grünerite is associated with magnetite, garnet and fayalite. The color is greenish-brown and the pleochroism quite noticeable. The grünerite described by Kreutz from La Mallière near Collobrières, fragments of which are in my possession, is less highly colored and is associated with only magnetite and garnet.

By plotting the indices of grünerite from Mount Humboldt, the Pyrenees and the French grünerite, the alpha index of the La Mallière specimen, as given by Kreutz falls considerably below the line connecting the values of the other specimens. However, a redetermination of these indices on the original material convinced me that the alpha index is undoubtedly higher than 1.672. In several instances I found that alpha does not go below 1.679. Also beta is a trifle higher than 1.697. Thus the indices fit well in the curve connecting all known grünerites.

Some irregularities appear in the central part of the diagram. It is especially apparent in the V. Silvberg amphibole (6), containing 14.67% of $H_2Mn_7Si_8O_{24}$, which has surprisingly high indices when compared with the preceding Krivoi Rog amphibole (5), in which manganese is absent, and with the Mount Humboldt grünerite (7), which has a small amount of this oxide. Dannemorite (12) and the grünerite from La Mallière (10), in which the sums of the iron and manganese silicates are almost equal, agree fairly well, although in the former much of the iron is replaced by manganese. The writer does not attempt any explanation of these peculiarities; the diagram merely records the facts. Apparently, there are still certain factors influencing the refractive indices which are, at present, not clearly understood.

From theoretical considerations Sundius infers that the graphical relationships of chemical composition and optical properties ought to be represented by straight lines. The deviation therefrom in the Mount Humboldt grünerite he explains by "some abnormal composition of the analyzed specimen" or by "some inexactitude in the analysis" (p. 339). Neither supposition is warranted. The grünerite schists at Mount Humboldt extend over the whole hill, covering an area of about one square mile. Thus I was fortunate in having for analysis abundant material and much of it of unusual purity. Furthermore, the agreement of the optical properties of this analyzed grünerite with the grünerite from various other outcrops, scattered all over the hill, is sufficient proof that the grünerite of Mount Humboldt is of uniform composition. The same agreement was found with grünerites in the eastern part of the Marquette district and likewise with those in the eastern part of the Mesabi district, Minnesota. On the other hand, in the extreme western part of the Marquette district, at Michigamme, grünerite is found with considerably higher indices (9), the values approaching closely to those of the La Mallière material studied by Kreutz. The grünerite at Champion, between Michigamme and Mount Humboldt, has also high indices. The only solution is to arrange the indices in curves which rise rapidly with the increase of iron. The new grünerite from the Pyrenees fits well in such a curve, while there is no place for it in the straight line diagram of Sundius.

Since the above was written the author had another opportunity to study grünerite in the vicinity of Michigamme. At the abandoned Michigamme Mine the mineral occurs abundantly and is of the type showing high refractive indices. Material was also collected at the abandoned Spurr Mine and at the Imperial Mine. In the localities just mentioned it was noted that the indices varied, even in specimens from the same locality. They were, however, always lower than the values obtained from the Michigamme Mine: $\alpha = 1.659 - 1.665$; $\beta = 1.676 - 1.682$; $\gamma = 1.690 - 1.697$. A determination of ferrous iron and manganese, in a specimen with low indices, gave approximately 32% FeO and 2.2% MnO.

Sundius gives at the value of $2v_\alpha = 93°$, while the writer found for varieties showing low indices, $2v_\alpha = 60°$. Hence it is apparent that grünerite displays a considerable variation in its optical properties and that it is not safe to draw conclusions from a single specimen.

CUMMINGTONITE—GRÜNERITE—DANNEMORITE SERIES

The percentage after the author's name gives the proportion of the ferromanganese silicate to the magnesium silicate. If a considerable amount of manganese is present, the manganese silicate is added in parentheses.

	α	β	γ
1) Bijiki schist, Michigamme, (Sundius) 60.67%	1.655,	1.669,	1.686
2) Uttersvik (Sundius) 63.81% (14.35)	1.656,	1.672,	1.686
3) Strömshult (Sundius) 72.59% (11.66)	1.663,	1.682,	1.699
4) Cummington (Sundius) 77.71%	1.666,	1.684,	1.704
5) Krivoi (Kunitz) 79.30%	1.667,	(1.683)	1.698
6) V. Silvberg (Sundius) 80.68% (14.67)	1.670,	1.690,	1.706
7) Mount Humboldt (Richarz) 84.97%	1.666,	1.684,	1.700
8) Pierrefitte, Pyrenees (Warren) 89.08%	1.676,	1.693,	1.707
9) Bijiki schist, Michigamme (This note) 90% (?)	1.677,	1.697,	1.714
10) La Mallière (Kreutz and this note) 90.54%	1.679,	1.679,	1.717
11) Collobrières (U.S.N.M., this note) 91.5% (?)	1.686,	1.708,	1.725
12) Dannemora (Sundius) 90.42% (20.62)	1.673,	1.698,	1.713

The reference to W. Kunitz is contained in: "Die Isomorphieverhältnisse der Hornblendegruppe," *N. Jahrb. f. Min.*, etc., Beilageband **LX**, Abtlg. A, p. 189, 1929. The compositions of 9 and 11 are hypothetical, computed from the indices.

A BARITE VEIN CUTTING GRANITE OF SOUTHEASTERN MISSOURI

W. A. TARR, *University of Missouri*

INTRODUCTION

The barite vein described in this paper was discovered by the writer in 1922. Since then, he has paid several visits to the locality and collected more material for study. The vein occurs along the west face of the south opening in Schneider's granite quarry, which is about three-quarters of a mile north of Graniteville, Iron County, Missouri. The vein is developed for 100 feet or more along a fault fissure that strikes N. 78° W. and dips 78 to 80° N.E. The amount of movement along the fault plane is unknown, but the evidence indicates that it was not large. There are numerous other fault fissures in the quarry, some of which are parallel to the one containing the barite vein. Another set of fissures that strike a few degrees north of west also occurs. Some of these fissures are fault planes but others are evidently only major fissures in the granite

The quarry is opened in a coarse, red, slightly porphyritic granite. This granite is cut by a mass of granite porphyry that divides the quarry into two parts. The granite porphyry strikes parallel to the east-west set of faults and fissures. At the east side of the south pit of the quarry, there is another exposure of granite porphyry that is probably related to the larger mass immediately to the north. The granite has a fairly uniform texture and color. It is composed of microcline, plagioclase, orthoclase, quartz, and a little biotite (now largely altered to chlorite). The feldspars constitute 72.5 per cent of the rock and the quartz (with some minor minerals) the remainder. The minor minerals are pyrite, magnetite, hematite, fluorite, minute garnets, and a few shreds of muscovite.[1]

THE BARITE VEIN

The barite vein is well exposed along the west face of the south quarry. The upper part of the vein is badly weathered, but much excellent material was secured for study from the lower parts and from newly opened portions.

The vein varies in thickness and does not exceed four inches in width at any point. It pinches out completely at some places along the exposure. Usually, it is completely filled from wall to wall, but occasional cavities occur. Bladed crystals of barite form the walls of these cavities.

---

[1] Tarr, W. A. and Neumann, L. M., A Study of the Effects of Heat on Missouri Granite: *Univ. of Mo. Bulletin, Eng. Exper. Station,* ser. 14, p. 13, **1914**.

The important minerals of the vein, in the order of their abundance, are barite, pyrite, and fluorite. Two other minerals occur, one of which has been tentatively identified as saponite, a very rare hydrous magnesium aluminum silicate. The other is galena.

Most of the barite is of a dark red color (it strongly resembles red orthoclase) due to included hematite, but some of it is pink, flesh colored, white, or even transparent. The transparent variety always occurs as a portion of the interior of a crystal. The barite possesses its usual bladed form, which is the mode of occurrence that produces the rounded, bladed masses so common in residual barite deposits. The blades cross the vein from wall to wall, either straight across or diagonally.

The pyrite occurs as a thin coating (minimum thickness 0.2 mm.) along the wall of the vein, as large crystalline aggregates, and as small crystals included in the barite. The pyrite deposited on the vein wall is, on the inner surface, always covered with crystal faces. These crystals may attain a diameter of one and one-half inches, and crystal aggregates up to two inches are fairly common. The crystals show a radiating internal structure. The pyrite crystals in the barite are all small, one or two millimeters in diameter. The most common crystal forms are cubes, which may or may not be modified by octahedrons. A few cubes modified by pyritohedrons were noted, as were also a few fairly well developed pyritohedrons.

The fluorite occurs as crystals or crystalline masses. A few crystals one-half inch in diameter were found, but the majority were less than one-fourth of an inch. The fluorite is purple, yellow, and transparent. The purple fluorite is surrounded by the yellow, but the line between the two is sharp. The yellow color fades out into the transparent material. The cubic forms predominate, but some crystals are modified by octahedrons. A few distorted and flattened cubic forms were noted.

The galena occurs in small crystalline grains up to one-half inch across. Very little galena occurs in this vein, but it is fairly abundant in a parallel fissure in the east part of the quarry, where it occurs in crystals up to one-half inch across.

The discovery of what is believed to be saponite is interesting.

This rare mineral is reported from very few localities. It occurs in this vein in soft waxy masses, found in cracks and openings in the pyrite or between the pyrite and other minerals. It is very infusible, turns black on heating, does not react with cobalt nitrate, contains much water, and is insoluble. Saponite is reported by Dana to be decomposed by sulfuric acid, but if this mineral is so affected it is with much difficulty. Specific gravity tests show it to be slightly heavier than the values given by Dana, but this is probably due to the impossibility of removing all the pyrite.

Alteration of the pyrite by ground waters has formed a little gypsum, melanterite, limonite, and hematite. A thin coating of lead sulfate occurs on the galena, where it is associated with the pyrite.

SEQUENCE OF MINERAL DEPOSITION

The sequence of deposition of the three major constituents is (1) pyrite, (2) fluorite, and (3) barite and pyrite. Where galena occurs, its deposition followed that of the pyrite. The pyrite was deposited on the wall of the fault fissure, and may completely fill the vein. The larger crystals grew in the wide portions of the fissure. In places, there is only a thin skin of pyrite on the walls. Locally, if the wall rock was shattered, pyrite (or fluorite) was deposited in the granite.

The fluorite is next in age to the pyrite and was deposited on it (there is some evidence that the periods of deposition of these two minerals overlapped slightly). Fluorite was also deposited on the wall where no pyrite had been deposited.

The barite is the youngest of the three minerals, and was deposited on either or both of the others and also occasionally directly upon the granite wall. Throughout most of the period of barite deposition, pyrite was being deposited with it, as is shown by the inclusions of small pyrite crystals in the barite. During the early stages of barite deposition, it overlapped the fluorite deposition. As noted above, if galena occurs it is younger than pyrite.

The saponite is clearly later than all the other minerals, and its formation is probably connected with the weathering of the upper part of the vein. Its high water content and physical properties make it an impossible member of the original group of minerals. The detailed description and origin of the saponite will be given in another paper.

Other fissures in the quarry show pyrite mineralization. In Sheahan's granite quarry, about one-half mile south, veins in the granite contain fluorite, zinnwaldite, quartz, pyrite (abundant), and rarely molybdenite, galena, and magnetite. These veins show that mineralization has occurred in this and adjacent quarries.

ORIGIN

It can scarcely be doubted that this barite-pyrite-fluorite vein cutting the granite can be other than magmatic in origin. The solutions evidently followed the fault fissure upwards and deposited their minerals in the open spaces along the fissure.

The solutions were rich in iron sulfides, as is shown by the abundance of pyrite of more than one generation. The red color of the barite is due to hematite, and is the typical color of the igneous rocks of southeastern Missouri. The fluorite may have been the result of reactions of HF with calcium salts, or it may have been carried as CaF_2. It is an extremely common constituent of magmatic waters. The barium may have been transported as the sulfide, chloride, or even fluoride. Its deposition as the sulfate would have been due either to reactions with sulfate solutions in the fissure or to the oxidation of the rising sulfide solution. Iron sulfide was still present in the solution as it was deposited simultaneously with the barite.

The argument that the barite in this vein was leached from the surrounding or overlying granite can scarcely have much weight. Granites are not leached to secure such a mineral. Furthermore, the presence of the fluorite and pyrite must be accounted for, and granite is no more a probable source for them than for barite. In short, these minerals were unquestionably deposited from warm waters that came from below.

The real significance of this barite vein lies in its occurring in the granite 15 to 20 miles from the important barite district of Washington County, Missouri. Some years ago, the writer[2] described these barite deposits, and at that time advocated a magmatic origin for the deposits. The paragenesis of the minerals in those deposits showed (1) quartz and chalcedony, (2) pyrite or marcasite, (3) galena and sphalerite, and (4) barite. This order was always the same whether all the minerals were present or not. For the minerals that occur in the barite vein in granite, the order is the same, save for the overlapping of the pyrite and barite. No quartz or chalcedony occurs in this vein, and no fluorite occurs in the barite district to the north. The characteristics of the primary deposits in the barite district are those of the shallow-vein type, and the mineralogy of this barite vein in the granite indicates that it belongs to the same type.

---

[2] Tarr, W. A., The Barite Deposits of Missouri: *Univ. of Mo. Studies,* vol. **3,** no. 1, 1918; The Barite Deposits of Missouri: *Econ. Geol.*, vol. **14,** 1919, pp. 46–67.

The occurrence of the barite vein in the granite (which undoubtedly also occurs under the sedimentaries in the barite district of Washington County to the north) is confirmatory evidence of the conclusion, previously reached, that the solutions which deposited the barite in the dolomites of Washington County were of magmatic origin. The solutions depositing the vein and those responsible for the barite deposits to the north were undoubtedly similar, though as the latter deposits were stratigraphically higher the solutions depositing them were undoubtedly cooler. However, although both deposits are of magmatic origin, they may not have been deposited by solutions from the same part of the magma; which would account for the minor differences in mineralization.

The recent attempt by Dake[3] to account for these barite deposits by the time-worn method of concentration of barite during the weathering of dolomites, ignores so many fundamental chemical factors (the use of which he regards as leading to "much unsound geological reasoning") that his suggestions, which involve chemical laws in spite of his refusal to recognize them as such, belong with the long discarded views of Werner or Sandberger. He argues against an origin by rising solutions, but offers no source for the barium sulfate, iron sulfides, quartz, chalcedony, or galena, all of which must be adequately accounted for since they occur intimately associated. In fact, Dake offers no suggestion as to solvents, means of transportation, or precipitating agents. Nor does he discuss the paragenesis of the minerals, or explain why the deposits are restricted to the areas where they are found.

Other barite deposits in different formations occur in Missouri, and as these also are localized it would seem necessary to discover some agency capable of transporting large quantities of barium under restricted conditions in order to explain the occurrence of the barite deposits of the state. It is true the world over that localized mineral deposits, such as these barite deposits, are generally connected with igneous rocks. Recently, Adams[4] has advocated a hydrothermal origin for the barite in Alabama, where the deposits are similar to those of Missouri. These deposits have previously been regarded as residual concentrations.

---

[3] Dake, C. L., Geol. of Potosi and Edgehill Quadrangles, *Mo. Bur. of Geol. and Mines*, vol. **23**, 1930, pp. 198–208.

SUMMARY

This vein (with its simple mineralogy of barite, pyrite, and fluorite) cutting granite is believed to be of magmatic origin, and the solutions depositing it to have arisen from below along a fault plane. The discovery of such a vein in granite not many miles from the large important barite district to the north points to a magmatic source also for the barite in that region, as was advocated in 1916 by the author.

---

[4] Adams, G. I., Hydrothermal Origin of the Barite in Alabama: *Econ. Geol.*, vol. **26**, 1931, p. 772.

DESERICITIZATION: A PROCESS OPERATIVE DURING HIGH TEMPERATURE MINERALIZATION

ROBERT E. LANDON, *Colorado Springs, Colorado*

INTRODUCTION

The alteration of orthoclase and other feldspars to sericite is a well-known and well-understood phenomenon. The feldspars of granitic rocks are commonly found altered to white mica, or sericite, in the vicinity of veins or fractured zones through which have passed more or less high-temperature solutions. The reverse change, that is from sericite to orthoclase, is not nearly so common nor so well understood. The alteration of muscovite or white mica to orthoclase has been recognized by Butler and Vanderwilt[1] in their study of more or less high-temperature mineralization in the molybdenum deposit at Climax, Colorado, and more recently a paper by Butler[2] treats of the same general topic. Butler[3] refers to the replacement of sericite by orthoclase as "orthoclasization." In this paper the writer describes the case of the mineralization of a previously sericitized granodiorite in which it seems conclusively evident that a similar change has taken place. The process is named "desericitization." The term refers to the destruction of sericite without regard to the nature of the mineral causing the destruction. In this respect the term differs from "orthoclasization" of Butler.

In the granodiorite stock at Santa Rita, New Mexico,[4] there occurs a brecciated zone in which intense mineralization has taken place. The minerals which were introduced are chiefly magnetite, quartz, orthoclase, and some copper mineral, now entirely oxidized. This locally brecciated granodiorite is known as the Whim Hill breccia. It is only in the Whim Hill breccia that the phenomenon to be described has been noted, all other specimens of the granodiorite examined having been found to be more or less completely sericitized.

---

[1] Butler, B. S., and Vanderwilt, John W., The Climax Molybdenum Deposit of Colorado: *Colo. Sci. Soc. Proc.*, vol. **12**, pp. 36–37, 1931.

[2] Butler, B. S., Influence of the Replaced Rock on Replacement Minerals Associated with Ore Deposits: *Econ. Geol.*, vol. **27**, pp. 1–24, 1932.

[3] *Loc. cit.*, p. 20.

[4] Paige, Sidney, *U. S. Geol. Survey Atlas, Silver City folio*, No. **199**, 1916.

PETROGRAPHY OF THE WHIM HILL BRECCIA

The structure of the breccia is illustrated in Fig. 1. The large fragment in the center of the photograph is about 1.5 inches across. Other fragments are somewhat larger but most measure about 1 inch in greatest dimension. The fragments are cemented by quartz, magnetite, oxidized copper minerals and orthoclase. In places open spaces exist between the fragments, although in such cases the fragments are generally covered with a film or crust of minerals similar to those which occur in the cement.

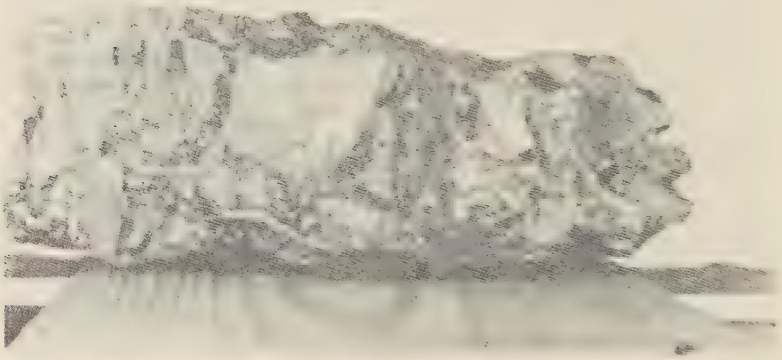


FIG. 1. Handspecimen of Whim Hill breccia.

A microscopic examination of the breccia discloses the texture of the original unaltered granodiorite to have been porphyritic granular. The phenocrysts presumably were orthoclase because there is no vestige of plagioclase twinning. The groundmass was probably quartz, orthoclase, plagioclase, and biotite.

The present mineral assemblage is illustrated in Fig. 2. The field shows two fragments of altered granodiorite separated by a mineralized fracture. Mineralization in the fracture consists of quartz, magnetite, and a small amount of orthoclase. The porous nature of the veinlet is shown by the presence of open spaces in the thin section. The fragments of granodiorite consist largely of sericite bordered by fresh, unaltered orthoclase in the vicnity of the fractures.

Other specimens under the microscope show that the interior of the granodiorite fragments carry bleached chlorite whereas the peripheral portions carry instead green biotite.

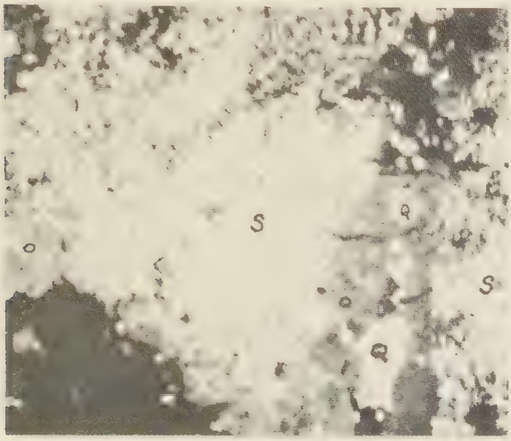


FIG. 2. Photomicrograph showing desericitization in Whim Hill breccia. *S*, white areas to both sides of veinlet, sericite. *O*, gray areas bordering sericite areas, orthoclase. *Q* in center of fracture, quartz. The dark areas in the fracture consist of quartz in extinction, opaque magnetite, and open space. Nicols, crossed. Magnification, about 12×.

THEORY OF MINERALIZATION

Three explanations of these facts are possible. The first suggests that after the fracturing of the fresh granodiorite hot magnetite-bearing solutions were introduced. In the open spaces between the rock fragments temperatures were too high for the formation of sericite and chlorite, but in the interior of the fragments these minerals could form. Under this hypothesis magnetite deposition and sericitization went on contemporaneously.

The second hypothesis states that after the solidification and crystallization of the granodiorite fracturing took place. During this process the rock was cooling, and exerted a cooling influence on the first of the mineralizing solutions to arrive. At this time the rock was sericitized. As mineralization progressed, temperatures increased, so that some of the sericite and chlorite previously produced was destroyed. Sericitization and chloritization were thus a prelude to the main magnetite mineralization, during which fresh orthoclase both filled fractures and replaced sericite.

The third hypothesis is as follows: The rock was sericitized and chloritized during one period, and in a distinctly later period was desericitized and dechloritized. Additional fresh orthoclase, quartz, and magnetite were deposited in the open spaces between the fragments. Both desericitization and dechloritization were most effective near the margins of the fragments and along the borders of the orthoclase phenocrysts.

The principal objection to the first hypothesis which attributed the change from sericitized to non-sericitized areas to differences of temperature in the mineralizing solutions, is found in the small scale in which these variations occur; they being well shown in the field of view of the microscope. It is hardly reasonable to assume that the temperature differences in such small scale distances would be large enough to account for the very marked mineralogical contrasts.

If sericitization constituted the prelude to magnetite mineralization it might be expected that a second stage of sericitization would follow the magnetite mineralization as the solutions cooled. Such, however, was not the case.

On the whole it seems probable that sericitization was an early and perhaps protracted process which effected the entire granodiorite intrusive. This period of alteration was distinct from the later process of metallic mineralization, which in the Whim Hill breccia was of such a nature as to produce orthoclase, quartz, and magnetite. The thermal and chemical nature of the solutions attending the two stages were apparently quite different.

The retention of outlines of phenocrysts and brecciated fragments proves the constancy of volume during mineralogical change, both from orthoclase to sericite and the reverse. Table 1 shows

Table 1. Losses and Gains in Alteration of Orthoclase to Sericite, Based on the Assumption that Volume Remains Constant

Specific gravities: orthoclase, 2.57; sericite, 2.76. Data from "Dana's Textbook of Mineralogy" 3rd ed., by W. E. Ford, John Wiley and Sons, Inc., New York, 1922, pp. 458 and 561.

Oxides	Composition		Weight of 1cc.		Gain in grams	Loss in grams
	Orthoclase	Sericite	Orthoclase	Sericite		
SiO_2	64.7%	45.2%	1.66g	1.25g		0.41g
Al_2O_3	18.4	38.5	0.47	1.06	0.59g	
K_2O	16.9	11.8	0.44	0.33		0.11
H_2O		4.5		0.12	0.12	
Total	100.0%	100.0%	2.57g	2.76g	0.71g	0.52g

losses and gains during the alteration of 1 cubic centimeter of orthoclase to sericite, based on the assumption that the volume remains constant.

Table 1 may also be used to show the gains and losses in the alteration of sericite to orthoclase by merely reading the gains as losses, and the losses as gains. During this stage some of the sericite which formed during the first stage was destroyed by the orthoclase-bearing solutions. The new orthoclase deposited in the veinlets together with quartz and magnetite, and some of it worked its way into the fragments replacing sericite. Much of this replacement appears to have followed the crystallographic lines of the primary orthoclase of the granodiorite since restored phenocrysts show simultaneous extinction of all areas. It was also during this stage that bleached chlorite to a minor extent altered to green biotite.

SUMMARY

The observations may be summarized as follows:

(1) Whim Hill breccia consists of sericitized granodiorite fragments. Some fragments contain bleached chlorite in their centers.

(2) Fresh orthoclase, quartz, magnetite, and copper minerals partially fill the interstices between the fragments. Fresh orthoclase also replaces sericite within the brecciated fragments along their margins.

(3) The replacing orthoclase restored the original feldspar structure as indicated by the simultaneous extinction of all areas within the outlines of a phenocryst.

(4) Small shreds of bleached chlorite occur in the centers of the granodiorite fragments, but near their borders in the vicinity of the fresh orthoclase, green biotite is present.

CONCLUSION

These facts lead to the conclusion that high-temperature solutions carrying the chemical constituents of orthoclase can replace sericite, and that the replacing orthoclase can assume a crystallographic orientation and structure similar to that of the first generation.

ACKNOWLEDGMENTS

The writer is greatly indebted to the Nevada Consolidated Copper Company for the privilege of collecting specimens in their

mine at Santa Rita. He also wishes to express his thanks to Dr. B. S. Butler of the University of Arizona, and Dr. E. S. Bastin of the University of Chicago for their helpful criticism in the preparation of the article.

NOTES AND NEWS

NOMINATIONS FOR OFFICERS OF THE MINERALOGICAL SOCIETY OF AMERICA FOR 1933

The Council has nominated the following for officers of the Mineralogical Society of America for the year 1933:

PRESIDENT: Herbert P. Whitlock, American Museum of Natural History, New York City.

VICE-PRESIDENT: Frank N. Guild, University of Arizona, Tucson, Arizona.

SECRETARY: Frank R. Van Horn, Case School of Applied Science, Cleveland, Ohio.

TREASURER: Waldemar T. Schaller, United States Geological Survey, Washington, D.C.

EDITOR: Walter F. Hunt, University of Michigan, Ann Arbor, Michigan.

COUNCILOR (1933–1936): Kenneth K. Landes, University of Kansas, Lawrence, Kansas.

The thirteenth annual meeting of the Society will be held December 28–30, 1932, at Harvard University, Cambridge, Massachusetts. It is planned to publish in the December issue of the Journal a *preliminary* list of titles of papers to be presented before the Society at its annual meeting. In order to appear on the advance program, titles of papers should be in the hands of the Secretary by *November 10*.

FRANK R. VAN HORN, *Secretary*

REPORT OF THE COMMITTEE ON NOMENCLATURE MINERALOGICAL SOCIETY OF AMERICA, 1932

TO THE FELLOWS AND MEMBERS OF THE MINERALOGICAL SOCIETY OF AMERICA:

The report of the Committee on Nomenclature has been mailed to all fellows and members. Please read it carefully and preserve your copy. If you have any suggestions to make, please send them to the Chairman, Dr. W. T. Schaller, U. S. Geological Survey, Washington, D.C., before November 1, 1932. The report, with any comments by the membership, will be presented to the Society at the annual meeting to be held in Cambridge, Mass., this coming December, 1932. Please be prepared to vote on its acceptance or amendment or rejection, without a full reading of the report at the meeting.

WALDEMAR T. SCHALLER, *Chairman*

PROCEEDINGS OF SOCIETIES

MINERALOGICAL SOCIETY OF GREAT BRITAIN AND IRELAND

MINERALOGICAL SOCIETY, *June 7th*—SIR JOHN S. FLETT, President, in the chair.

Dr. J. E. DRUGMAN and Mr. MAX H. HEY: *Legrandite, a new zinc arsenate.* A yellow transparent mineral on a single specimen of blende proved to be a new zinc arsenate. Chemical, optical, goniometric and X-ray measurements were made, and the name legrandite is proposed for the new mineral, the formula of which is $Zn_{14}(AsO_4)_9OH \cdot 12H_2O$.

DR. W. F. P. MCLINTOCK: *On the metamorphism produced by the combustion of hydrocarbons in the Tertiary sediments of south-west Persia.* At various localities in south-west Persia the escape and combusiton of gas or oil have resulted in the brecciation, partial fusion, and crystallization of calcareous marls with the formation of crystalline rocks consisting of pyroxene (diopside, aegirine-augite and aegirine), wollastonite, pseudo-wollastonite, bytownite, melilite, and leucite, with glass, recrystallized calcite, and anhydrite. In the field the rocks resemble vesicular igneous types but microscopic examination and chemical analyses, accounts of which are given, prove them in all cases to be metamorphosed sediments.

MR. F. A. BANNISTER: *On the determination of minerals in platinum concentrates from the Transvaal by X-ray methods* (with chemical analyses and syntheses by Mr. M. H. Hey): X-ray rotation photographs have been used to distinguish and select for chemical analysis the various platinum- and palladium-bearing minerals present in the concentrates of Bushveld platinum ore. The name cooperite is retained for PtS, tetragonal, space-group D_{4h}^9. The face-centered unit cell with edges $a=4.91$, $c=6.10$ Å., contains 4PtS. The atomic coordinates for platinum in this cell are $\frac{1}{4}\,\frac{1}{4}\,0$; $\frac{3}{4}\,\frac{3}{4}\,0$; $\frac{1}{4}\,\frac{3}{4}\,\frac{1}{2}$; $\frac{3}{4}\,\frac{1}{4}\,\frac{1}{2}$, and for sulphur:—$0\,0\,\frac{1}{4}$; $0\,0\,\frac{3}{4}$; $\frac{1}{2}\,\frac{1}{2}\,\frac{1}{4}$; $\frac{1}{2}\,\frac{1}{2}\,\frac{3}{4}$. The structure is a simple type of fourfold coordination built up from plane PtS_4 groups and tetrahedral SPt_4 groups, the Pt-S distance being 2.32 Å. Synthetic PtS has been prepared and is identical with the mineral cooperite. Laurite (RuS_2) occurs in small pyritohedral-cubic crystals and has the pyrite structure with unit-cell edge $a=5.59$ Å. The third mineral $PtPdS_2$, containing about 5 per cent. Ni, is also tetragonal with unit-cell edges $a=6.37$, $c=6.58$ Å. The unit cell contains $4PtPdS_2$ and the space group is D_{4h}^2. The name Braggite is proposed for this mineral as being the first discovered by X-ray methods.

MR. JOHN PARRY, MR. ALPHEUS F. WILLIAMS AND DR. F. E. WRIGHT: *On Bultfonteinite, a new fluorine-bearing hydrous calcium silicate from South Africa.* This new mineral was found in the Bultfontein and Dutoitspan diamond mines at Kimberley and in the Jagersfontein mine in Orange River Colony. It forms pale pink globular aggregates of radiating needles, and has much the appearance of natrolite. Analysis gives the formula $2Ca(OH_9F)_2 \cdot SiO_2$. From the manner in which the mineral is decomposed by water and by dilute acids, a formula written as $Ca(OH_2)SiO_2 \cdot Ca(OH, F)_2$ is suggested. Goniometric and optical examination of the minute crystals shows them to be triclinic, but much complicated by polysynthetic twinning. The mineral is related to afwillite with the addition of $Ca(OH)_2$ and CaFe, and the nearest ally is custerite [$CaO \cdot Ca(OH, F)_2 \cdot SiO_2$].

BOOK REVIEWS

DIE FELDSPÄTE UND IHRE PRAKTISCHE BESTIMMUNG, Karl Chudoba. 50 pages, 46 text figures and 4 tables. E. Schweizerbart'sche Verlagsbuchhandlung, *Stuttgart*, **1932**. Price with paper covers, Rm. 5; linen covers, Rm. 6.

This excellent pamphlet deals chiefly with the plagioclase feldspars. It gives brief descriptions with good curves of all the important methods for their determination. It includes a brief description of the Fedorov stage and its use in determining plagioclases. With the stage sections are oriented and the feldspar determined by one of the ordinary methods, such as the maximum extinction method, combined carlsbad and albite twin method, or the so-called rhombic section method.

The printing, illustrations, and make-up of the pamphlet are excellent. The book should be in every petrographic laboratory.

Esper S. Larsen

MIKROSKOPISCHE CHARAKTERISTIK DER GESTEINSBILDENDEN MINERALIEN, Karl Chudoba. 8 vo. VIII+213 pages, 306 figures; 29 pages of tables. Herder and Co., *Freiburg im Breisgau*, **1932**.

Chudoba's new book on the "Microscopic Characteristics of Rock-forming Minerals" is perhaps too brief for the elementary student, but contains much of interest. For example, less than ten pages are devoted to an explanation of the "physical properties of minerals which find use in the microscopic determination of minerals." The main part of the book (160 pages) is devoted to descriptions of the minerals, which are classified as isotropic, uniaxial, biaxial, and opaque. The description of each mineral is well arranged and distinguishing features are emphasized. The descriptions are illustrated by numerous diagrams and photomicrographs, many of the latter previously published by Weinschenk. It seems unfortunate that recent work on the constitution and properties of some minerals receives so little attention—for example, the studies of melilite by Ferguson and Buddington (*Am. Jour. Sci.*, **L**, 1920, p. 131), Winchell (*Am. Jour. Sci.*, **VIII**, 1922, p. 375), Gossner (*Chem. Erde*, **II**, 1926, p. 103), Berman (*Am. Mineral.*, **XIV**, 1929, p. 389), Warren (*Zeit. Kryst.*, **LXXIV**, 1930, p. 131), and Bragg (*Zeit. Kryst.*, **LXXIV**, 1930, p. 237–305) are disregarded in the formulas used by Chudoba.

A. N. Winchell

CORRECTION

In *The American Mineralogist*, July, Vol. **17**, page 338, the locality given for the green variety of pumpellyite, Mill Creek, is wrong. Mr. Vonsen states that it was found near Porter Creek, Sonoma Co., two miles northwest of River Road and about eight and one half miles southwest of Healdsburg.